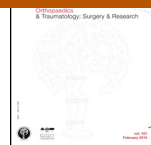




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Original article

Effectiveness of CT for the detection of glenoid bone graft resorption following reverse shoulder arthroplasty

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ABSTRACT

Introduction: Glenoid bone grafting is often used in cases of reverse shoulder arthroplasty (RSA) with glenoid deficiency. Additionally, bony increased-offset RSA (BIO-RSA) uses a cylindrical bonegraft harvested from the humeral head and is positioned beneath the glenoid baseplate to increase lateralization. Postoperative computed tomography (CT) has been used to detect glenoid bonegraft resorption, which is typically identified by a gap between the bonegraft and baseplate; however, CT images are often degraded by implant metal artifact. The purpose of this CT imaging study was to determine if a simulated bonegraft resorption gap is detectable following RSA with glenoid bone grafting.

Hypothesis: CT is unable to detect bone graft resorption following reverse shoulder arthroplasty conducted with bone grafting beneath the glenoid baseplate.

Materials and methods: RSA with glenoid bone grafting was performed on four cadaver shoulders. Glenoid bonegraft resorption gaps were simulated by fixing the implant at six different gap widths (0, 1, 2, 4, 6 and 8 mm). Clinical CT scans were acquired for each gap resulting in 6 scans per specimen. Two experienced observers (blinded) analyzed DICOM images in the axial and coronal directions, and measured gap widths using Mimics® software. Each observer had access to approximately 200 images per condition per specimen.

Results: The sensitivity of CT imaging to positively identify bonegraft resorption was 38%, with an accuracy of 46%. Inter-observer agreement was 92%. Observers tended to visualize no-gap for most conditions. Resorption gap width measurements were consistently underestimated.

Discussion: Metal artifact prevented identification of simulated bonegraft resorption gaps and observers most often determined that there was bonegraft-to-implant “healing” on CT, when in fact a gap was clinically present. This study illustrates the need for more effective imaging techniques to determine if bonegraft resorption has occurred following RSA.

Level of evidence: Level IV. Basic Science; Cadaveric Study.

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1. Introduction

Reverse shoulder arthroplasty is an effective treatment for rotator cuff tear arthropathy, massive irreparable rotator cuff tears and comminuted proximal humerus fractures. Bone grafting of the glenoid is a commonly used technique to address glenoid bone deficiency and to assist with glenoid component lateralization. In cases of severe glenoid bone deficiency, the humeral head can be used

as a structural bonegraft secured to the native glenoid, with fixation obtained from the glenoid component baseplate. Additionally, glenoid bone grafting has been used as a method to increase glenoid component lateralization to decrease the common complication of scapular impingement and notching. The use of a cylindrical bonegraft harvested from the humeral head, and positioned beneath the glenoid baseplate has been termed “bony increased-offset reverse shoulder arthroplasty (BIO-RSA)” [1].

The long-term stability and survivability of these bonegraft constructs is in part due to osseointegration of the bonegraft with the native glenoid bone. Additionally, bone on-growth between the implant baseplate and the bonegraft is believed to be beneficial for long-term survivability. For bone on-growth to occur, contact between the baseplate and the bonegraft is required. Failure to

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achieve this on-growth may occur due to bonegraft resorption, micromotion due to poor initial implant stability, or insufficient compression of the bonegraft-implant interface.

Bone on-growth of porous coated implants has shown promising results in increasing the life of implants [2–6]. Bonegraft resorption may result in increased localized stresses and a degrading of implant fixation, which may potentially compromise implant survivability [7–9]. Postoperative computed tomography (CT) is an imaging modality used by surgeons to detect bonegraft incorporation or resorption. Although CT can be an effective imaging tool, image quality is often degraded by implant metal artifact. While algorithms for reducing implant metal artifact exist [10–12] and can be used clinically, these methods do not completely eliminate artifact. Given that the bony region of interest for structural glenoid bone grafting and the BIO-RSA is adjacent to the metal implant, it is reasonable to postulate that metal artifact may decrease the ability of surgeons to detect bonegraft incorporation or resorption.

The use of CT imaging has been reported as a means of observing healing of the bonegraft adjacent to a reverse shoulder arthroplasty [1]. However, the CT technique has not been validated in a controlled model. Thus, the purpose of this study was to determine if a simulated bonegraft resorption gap is detectable following BIO-RSA, using an in-vitro model imaged by CT. The accuracy and reliability of measuring the simulated bonegraft resorption gap width was quantified. We hypothesized that CT is unable to detect bone graft resorption following reverse shoulder arthroplasty conducted with bone grafting beneath the glenoid baseplate.

2. Materials and methods

Four fresh-frozen cadaveric shoulders (mean age: 56 ± 18 years) with preserved soft tissues and the humerus resected at the mid-shaft were used for this CT imaging study. An 8 mm thick cylindrical bonegraft was harvested from the humeral head and a BIO-RSA [13] was performed on each specimen by a fellowship trained shoulder surgeon with ten years of experience implanting RSA, using an Aequalis™ Reversed II Shoulder System (Tornier Inc., Bloomington, MN). A 29-mm diameter baseplate with an extended 25-mm post was implanted with a 36-mm glenosphere.

Six bone resorption gaps of varying width were simulated at the graft-baseplate interface of each specimen using precision custom fabricated (± 0.05 mm) plastic spacers. Resorption gaps were simulated in decreasing order (i.e. 8, 6, 4, 2, 1, 0 mm). To secure the baseplate and the bonegraft, only compression screws were used, with screws inserted parallel so that decreasing gaps were achieved by sequentially advancing the screws into the same existing holes. This method preserved bone integrity by avoiding repeated screw holes at varying angles. The plastic spacers were used to confirm the desired gap, but were removed prior to each CT scan. A clinical CT scan was done after each condition (6) for each specimen (4), for a total of 24 CT scans.

In order to avoid high air contrast, and artifact caused by large transitions in density, the density of joint fluid was simulated using buffered saline solution (Nerl Blood Bank Saline, Thermo Fisher Scientific Inc., Waltham, MA). The specimens were secured to avoid movement during CT scanning. Scanning was performed using a multi-slice scanner (GE Discovery CT750 HD) with clinical settings (140 KvP, 250 mm field of view, 1 mm slice increment, 1.25 mm slice thickness, resolution of 512×512 and 0.488 mm pixel size). These settings are standard at our centre to minimize metal artifact for patients with shoulder implants. Specimens were placed in the scanner in a manner consistent with patient placement. As such, the gap width dimension was oriented within the CT slice plane, where the pixel size is 0.488 mm, thus optimizing resolution of the gap width.

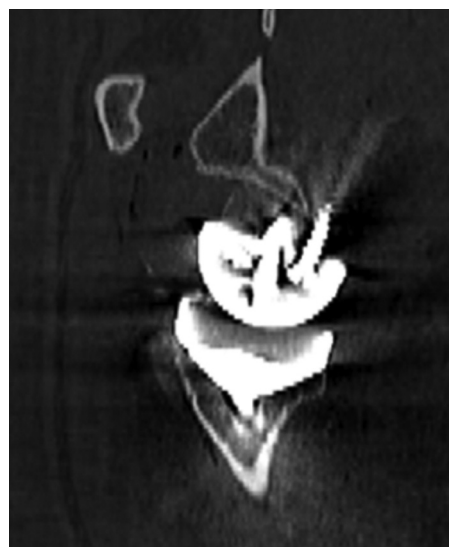


Fig. 1. A CT image in the coronal plane of a specimen with no gap (0 mm, full contact) between the reverse shoulder arthroplasty (RSA) baseplate and the bonegraft. The absence of the gap was accurately identified by both observers.

Computed tomography images in digital imaging in communications and medicine (DICOM) format were uploaded to medical imaging software (MimicsV. 15.01, Materialize, Leuven, BE). All identifying information was removed from the file names in order to blind observers (Figs. 1–4). Separately, two experienced observers viewed blinded and randomized specimen CT files. The observers were asked to review the imaging files to determine if a simulated resorption gap was present, and if present, to measure the gap width between the bonegraft and baseplate using the Mimics linear distance measurement tool. Observers were able to browse through DICOM images in the axial and coronal directions, which amounted to approximately 200 images per condition for a total of 4800 images for this study.

Statistical analysis was performed using a Fisher Exact test to determine if each observer could determine a simulated bonegraft resorption gap when present. A contingency table for diagnostic testing further indicated positive and negative identification of gap presence, from which we calculated sensitivity, specificity



Fig. 2. A coronal CT image of a specimen with a 4 mm simulated resorption gap, which was incorrectly reported by both observers as having no gap (0 mm).

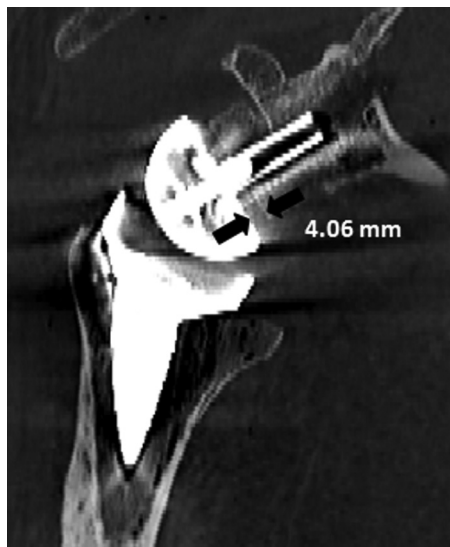


Fig. 3. A 4-mm simulated resorption gap (indicated by arrows) in the coronal plane between the bonegraft and baseplate was accurately measured by both observers using Mimics® linear measurement tool.

and accuracy of the imaging test, as well as measures of inter-observer agreement with Cohen's Kappa. A paired samples *t*-test was used for quantification of observer accuracy, and an inter-item paired-samples correlation was used to quantify agreement between observers in determining gaps in the same simulated resorption gap images.

3. Results

In scenarios where no simulated gap existed between the baseplate and the bonegraft, the observers correctly identified all but

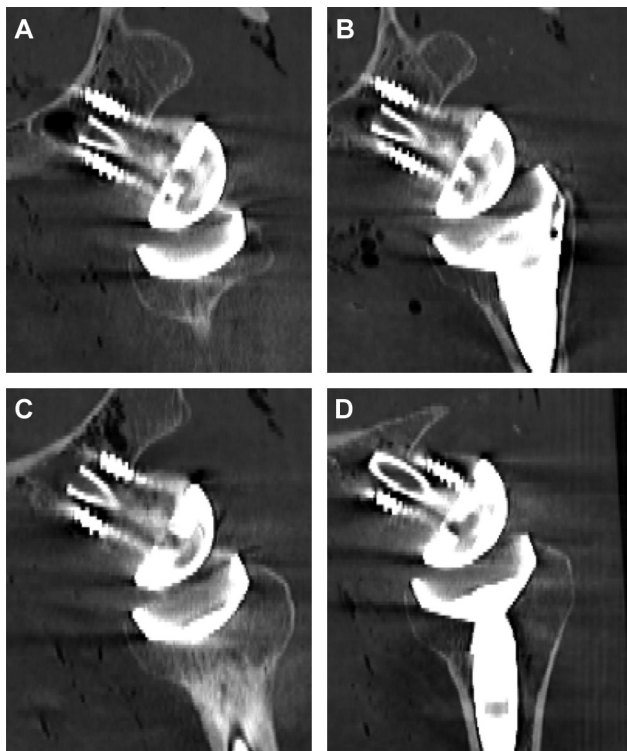


Fig. 4. Coronal CT images of simulated gaps that were incorrectly identified as 'no gap' by both observers. A. 1 mm gap. B. 2 mm gap. C. 6 mm gap. D. 8 mm gap.

Table 1

Accuracy of observed gap width measurements.

	Mean \pm SD (mm)	<i>p</i> -value
Actual–Observer 1	1.83 \pm 3.27	0.011
Actual–Observer 2	2.53 \pm 2.62	<0.001
Observer 1–Observer 2	0.70 \pm 1.82	0.073

Observer accuracy in measuring the actual gap width (mean \pm standard deviation) and associated *p*-values (Paired samples *t*-test). Both observers tended to underestimate gap width measurements. There was no significant difference between the observers.

Table 2

Contingency table for identification of gap presence.

	Cadaver gap (+) (Observer1 Observer2)	Cadaver no gap (–) (Observer1 Observer2)	Total (Observer1 Observer2)
CT (positive gap)	7 8	0 1	7 9
CT (no gap)	13 12	4 3	17 15
Total	20	4	24

Contingency table indicating positive and negative identification of gap presence for Observer1|Observer2 using CT measurements. The CT method was reliable at identifying no gap (negative) conditions, but at the cost of low reliability for identifying gap presence (positive) conditions. Sensitivity = 35%|40% (average = 38%). Specificity = 100%|75% (average = 88%). Accuracy = 46%.

one 0 mm no-gap condition (7 of 8 scenarios). However, in scenarios with small-simulated bone resorption gaps (1, 2 mm), experienced observers were only able to correctly identify the presence of a gap in 25% (4 of 16) scenarios. In scenarios with large simulated gaps (4, 6, 8 mm), the observers correctly identified that a resorption gap was present in 46% (11 of 24) scenarios.

Both observers tended to underestimate the gap width measurements ($p \leq 0.011$) (Table 1). In addition, there was no significant difference between the observers in making their measurements from CT ($p = 0.073$).

A contingency table for diagnostic testing indicates the positive and negative identification of gap presence using the CT method (Table 2). The sensitivity of the CT method, which is the ability of the imaging modality to correctly identify specimens with a gap, was poor at 38%. However the specificity of CT, which is the ability of the imaging modality to identify negative results, was good at 88%, meaning that if a CT imaged resorption gap was observed, then a true gap was likely present. Considering the identification of gap presence separately with small gaps (1, 2 mm) and large gaps (4, 6, 8 mm), Fisher Exact tests revealed that the CT measurement method was no better at distinguishing no-gap from large gaps ($p = 0.205$) than it was for small gaps ($p = 0.631$).

Agreement between the observers was high at 92% (Kappa = 82%), with a percent positive agreement of 78% (Table 3), and there was a significant correlation between observers in determining gaps when considering the same image (Inter-item paired samples correlation, $R^2 = 0.690$, $p < 0.001$). Also, a Fisher Exact test revealed that there was no significant difference between observers in correctly identifying gap or no-gap scenarios ($p = 1.000$).

Table 3

Inter-observer agreement.

	Observer 1	
	(+)	(–)
Observer 2		
(+)	7	2
(–)	0	15

Agreement between both observers was high. Overall % agreement = 92%. Agreement subtracting chance (kappa) = 82%. Percent positive agreement = 78%. Perfect agreement occurs when the lower left and upper right cells are 0.

4. Discussion

The ability to identify bonegraft resorption following structural glenoid bone grafting and BIO-RSA is important, as loss of the bonegraft's integrity may compromise implant survivability. While the use of CT imaging has been reported as a means of detecting resorption of the BIO-RSA bonegraft [1], this technique has not previously been validated to show that artifact from the implant does not impact an observer's ability to detect gaps at the implant-bonegraft interface. In this study, we simulated resorption gaps of various widths (including no resorption gap) in a controlled cadaveric model, with a joint fluid analog.

Our results indicate that experienced observers using CT were not able to identify simulated bonegraft resorption at the graft-baseplate interface of a BIO-RSA model. In general, observers performed marginally better with large gaps (4 to 8 mm) compared to small gaps (1 to 2 mm); however, each observer identified two out of four gaps for each of the 4 and 8 mm gaps, indicating that reliability in detecting large gaps did not increase with gap width. The high specificity (i.e. the ability to correctly identify no gap) came at a cost of low sensitivity (i.e. the ability to correctly identify a gap). This was due to the tendency of the CT metal artifact to occlude the gap, giving the appearance of graft healing. Consequently, observers tended to assume that there was no gap (0 mm) or "healing" whenever a clear gap was not evident. Even in scenarios that simulated almost complete graft resorption, observers assumed that "no gap" was present when no clearly defined bonegraft edge was visually apparent on the CT images (Fig. 2).

Reliable identification of simulated resorption gaps occurred when they were clearly demarcated. Fig. 3 shows an example of a 4 mm simulated resorption gap that is clearly demarcated by the contrast of a good-quality bonegraft. In this specimen, simulated resorption gaps were correctly identified and accurately measured by both observers for all large gaps (4 to 8 mm) simulated; however, this was not the case for small simulated resorption gaps (1 to 2 mm) in the same specimen using the same bonegraft, suggesting that metal artifact from the baseplate likely occluded these small gaps. Fig. 4 demonstrates several scenarios with simulated gaps that were incorrectly identified as 'no gap' by both reviewers.

Agreement between the observers was high, whether positive or negative, when attempting to identify the presence of a gap, even when corrected for chance using Cohen's Kappa. Moreover, there was no significant difference between the observers when measuring the magnitude of gap width. Therefore, while gap identification and gap width measurement was poor, the observers were generally in agreement with each other's perceptions of the CT images. This is corroborated by the fact that the observers performed their measurements independently, without consultation and blinded to the actual gap scenarios.

This study has found that clinical CT is inconsistent at visualizing the presence or absence of bonegraft resorption adjacent to a reverse shoulder arthroplasty glenoid baseplate. These results may apply to other techniques similar to the BIO-RSA model we tested, such as standard bone grafting techniques used with RSA, or staged bone grafting where the bonegraft is initially secured by the glenoid baseplate. It is likely that the gap would be more easily appreciated using standard X-rays parallel to the flat back of the baseplate. The resorption gap can be narrow and it may not traverse the full width of the baseplate. Thus, real-time visualization would be necessary to align the beam with the baseplate back, and to explore different vantages. C-arm fluoroscopy would likely be suitable for this.

There were potential limitations in this study protocol. In this in-vitro study, resorption gaps were simulated immediately following bonegraft placement, and in the absence of bone remodeling due to physiological resorption. Thus, it is unclear whether

physiological resorption, in the time leading to follow-up, may result in a more or less clearly defined resorption gap. The low number of specimens is likely not representative of bone density variance in the population. Thus, if the average patient's bonegraft has higher density than represented by our study, then average success may be better than our results; however, the opposite is also possible.

It is clear that metal artifact prevented simulated bonegraft resorption identification, and that without a visible resorption gap, the observers most often believed there was no gap. Metal artifact reduction algorithms may improve identification of large gaps, but are not likely to be effective for small gaps near the metal baseplate. Since any amount of resorption prevents proper bone on-growth, this study illustrates the need for a more effective imaging technique to determine if bonegraft resorption has occurred following RSA.

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Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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